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TECHNICAL report

USA-BRDEC-TR // 2520

An Evaluation of Three Commercial Processes for Recycling Used Military Antifreeze MIL-A-46153

by
Dwayne Davis

Report Date
June 1992

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Belvoir Research, Development and Engineering Center
Fort Belvoir, Virginia 22060-5606

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1992	Final

4. TITLE AND SUBTITLE An Evaluation of Three Commercial Processes for Recycling Used Military Antifreeze MIL-A-46153 (U)	5. FUNDING NUMBERS
6. AUTHOR(S) Dwayne Davis	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Belvoir Research, Development & Engineering Center Logistics Equipment Directorate Fuels and Lubricants Division, STRBE-FLH Fort Belvoir, VA 22060-5606	8. PERFORMING ORGANIZATION REPORT NUMBER 2520
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES POC: Dwayne Davis, (703) 704-3720	
12a. DISTRIBUTION/AVAILABILITY STATEMENT Distribution unlimited; approved for public release.	12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

The Belvoir Research, Development and Engineering Center (BRDEC) was requested by the USAF to assist in evaluating the effectiveness of commercially offered used antifreeze recycling systems. BRDEC was solicited for assistance because of its mission responsibility for military antifreeze and because it is the preparing activity for antifreeze under MIL-A-46153.

This report evaluates three commercial recycling systems using antifreeze samples collected and processed at both Tyndall AFB, FL, and McConnell AFB, KS. Seven sets of samples (each comprised of a recycled and the original used) were evaluated. A total of 11 laboratory tests were conducted on the samples.

14. SUBJECT TERMS	15. NUMBER OF PAGES
coolant recycling MIL-A-46153 antifreeze used coolant	32
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

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Section I

Background

In November 1988, the Headquarters Strategic Air Command at Offutt Air Force Base, Nebraska, initiated an Air Force Management and Equipment Evaluation Program (MEEP) project to evaluate the effectiveness of commercially offered used antifreeze recycling systems. The project was begun in hopes of finding an effective method of reducing the costs associated with the purchase of new antifreeze and the disposal of used antifreeze.[1] The study was conducted under MEEP project H88-24, "Antifreeze Recycling System." Shortly thereafter, the USAF asked for the assistance of the US Army Belvoir Research, Development and Engineering Center (BRDEC). BRDEC was solicited for assistance because of its mission responsibility for military antifreeze and because this Center is the preparing activity for antifreeze under Military Specification MIL-A-46153.

At the start of the MEEP project, only one recycling system—the Glyclean Antifreeze Recycling System made by FPPF Chemical Company of Buffalo, New York—was to be evaluated. Later, two other systems were included in the investigation. They are the Wynn X-Tend Mark X Power Flush System made by Wynn Oil Company of Azusa, California, and the Kleer-Flo Anti Freeze Recycler made by Kleer-Flo Company of Eden Prairie, Minnesota. All three systems incorporate similar methods to rejuvenate used antifreeze; namely, filtration of the used antifreeze to remove dirt and other solid contaminants, followed by reinhibition with proprietary compounds to replace the depleted inhibitors of the spent antifreeze. The Wynn system differs from the other two systems in that it is attached directly to vehicle radiators and it processes used coolant in individual vehicles. The Glyclean and Kleer-Flo systems process used antifreeze in batches which are collected from numerous vehicles.

Section II

Approach

The antifreeze samples used in this study were collected and processed by the USAF, then sent to BRDEC for laboratory evaluation. Used antifreeze was collected and processed at both Tyndall US Air Force Base (AFB) in Florida, and McConnell AFB in Kansas. Seven sets of samples, each comprised of a recycled sample and the original used sample, were evaluated. Four sets consisted of all military antifreeze, MIL-A-46153. Another set represented a mixture of commercial antifreeze and MIL-A-46153. The remaining two sets were composed entirely of commercial antifreeze. A total of eleven laboratory tests were conducted on the samples, including both standard American Society for Testing and Materials (ASTM)[2] and non-standard tests. Four tests were labeled sample performance tests (i.e., tests whose results were indicative of sample performance in an engine cooling system). Tests included in this category were:

- Foaming tendencies of Coolants in Glassware (D-1881),
- Corrosion Test for Engine Coolants in Glassware (D-1384),
- Corrosion of Cast Aluminum Alloys in Engine Coolants Under Heat-Rejecting Conditions (D-4340) and
- Cavitation-Erosion Corrosion of Aluminum Pumps With Engine Coolants (D-2809).

The remaining tests were labeled sample quality tests. Results of these tests were representative of the chemical and physical condition of the sample. Tests in this category included:

- Water in Engine Coolant Concentrate by the Karl Fischer Reagent Method (D-1123),
- pH of Engine Antifreezes, Antirusts, and Coolants (D-1287),
- Reserve Alkalinity (RA) of Engine Antifreeze, Antirusts, and Coolants (D-1121),
- Use of The Refractometer for Determining Freezing Point of Aqueous Engine Coolants (D-3321),
- Ash Content of Engine Coolants and Antirusts (D-1119) and
- Visual Appearance and Metal Analysis.

The RA and pH tests were conducted to obtain approximate measures of each coolant's buffering capacity or alkaline inhibitor content. In general, buffered coolants, which are moderately alkaline (i.e., pH above 7), decrease the corrosion rates of most metals found in engine cooling systems. For MIL-A-46153 antifreeze, RAs between 4mL and 8mL are found to give satisfactory field performance. Foam tests were performed to determine those samples with excessive foaming tendencies. Excessive foaming can result in poor heat transfer, reduced water pump efficiency, and loss of coolant.[3] These factors can cause engine overheating. The ash from antifreeze is the residue that remains after it is ignited. The inorganic inhibitors of coolants are the major contents of the ash. However, the ash is usually not a good measure of total inhibitor concentration because of the organic inhibitors which are lost after ignition. The ash content is included here for general quality information and to show those used samples which might have been excessively reinhibited. The water content and freeze protection tests were performed to obtain information concerning the general quality of the antifreeze solutions. The results were not used to evaluate each recycling system's effectiveness. The water content of the antifreeze solutions was dependent upon the freeze protection desired and adjusted by individual users according to the climate in their respective areas.

Glassware corrosion tests were performed to determine those samples which may be harmful from a metal corrosion standpoint. The glassware test discerns between coolants which are highly corrosive and those that offer acceptable corrosion protection. The measure of corrosion protection is based on the weight losses of six metal specimens under solution heated conditions. The specimens consist of metals commonly found in all coolant systems. The heat-rejecting aluminum corrosion test and the pump cavitation-erosion corrosion test were conducted to gain additional data on the corrosion protection of the coolants. The tests offer more definitive corrosion data than the glassware corrosion test due to the specialization of each test. The heat-rejecting aluminum corrosion test and the cavitation test evaluate a coolant's ability to prevent the corrosion associated with aluminum. The heat-rejecting aluminum test measures the particular aluminum corrosion found under heat-rejecting surface conditions as opposed to solution heated conditions of the glassware corrosion test. An example of heat-rejecting surface conditions is

found in aluminum cylinder head engines. The corrosion under heat-rejecting surface conditions is more severe than solution heated conditions due to the heat being applied directly to the metal. The pump cavitation test discriminates between those coolants which cause cavitation erosion-corrosion (i.e., pitting) of aluminum water pumps and those that do not. Unfortunately, due to limited quantities of sample, the special aluminum tests could only be performed on samples from the Glyclean system. These tests were conducted at Southwest Research Institute (SwRI) in San Antonio, Texas. The remaining non-ASTM tests—visual inspection and metal analysis using an atomic absorption (AA) spectrophotometer—were performed to determine the overall cleanliness of the samples. A coolant containing excessive amounts of rust or other sediment can clog coolant passages, and thereby cause overheating.

The ASTM methods requiring sample dilution prior to the test were modified for this study. Instead of diluting samples as prescribed in the method, samples were tested "as is" to determine the actual performance of the sample alone. Since the recycled sample would presumably be returned directly to a vehicle for use, it was felt test results would be more indicative of sample performance in the field without further dilution. In each system evaluation, test results of new MIL-A-46153 antifreeze mixed 50% by volume with corrosive water, were included for comparison with the used and recycled samples. The 50% concentration was chosen to approximate the antifreeze concentrations of the used and recycled samples. Final evaluation of system effectiveness was based on a comparison of the recycled sample test results to the used sample and the new MIL-A-46153 sample test results. For example, a recycled sample showing significant improvement over the used sample condition and having comparable quality with that of the new MIL-A-46153 sample would indicate an effective used antifreeze recycling system.

GLYCLEAN SYSTEM

The Glyclean unit comes assembled as shown in Figure 1. The system can process 25 to 100 gallons of used antifreeze per batch and uses both mechanical and chemical means to remove contaminants from used antifreeze. The used antifreeze is first loaded into the Glyclean unit. After the pH and freeze point are checked, a proprietary additive, the Glyclean Extender Additive, is added in amounts based on the pH.

The additive, along with 5 and 20 micron porosity filters, removes, dirt, scale, rust, and dissolved metals which are precipitated out of solution by the additive. FPPF Chemical states that the Glyclean additive acts as an inhibitor package, sequestering agent, and precipitating agent. After the additive is added to the used antifreeze, it precipitates and/or "ties-up" dissolved metals.[4] The Glyclean additive contains sodium hydroxide to precipitate any dissolved metal present in appreciable amounts. The precipitate is then removed by a series arrangement of the 5 and 20 micron porosity filters. The remaining trace amounts of metal are sequestered by an organic polymer to prevent possible precipitation in the recycled antifreeze. After most of the dissolved contaminants are removed or sequestered, additional Glyclean additive is added to reinhibit the used coolant.

Figure 1. Glyclean Antifreeze Recycling System

The Glyclean samples were obtained and processed at McConnell AFB, Kansas. Approximately 45 gallons of used antifreeze were processed through a Glyclean unit. The used antifreeze was collected from several vehicles, some containing military antifreeze (MIL-A-46153) and some containing commercial antifreeze. The exact commercial brand was unknown. The total used antifreeze composition was estimated to be 90% military and 10% commercial. Test results of samples processed through the Glyclean system are shown in Table 1.

Table 1. Test Data for Glyclean Batch

TEST	USED	RECYCLED	NEW MIL-A-46153	ASTM METHOD	ASTM D-3306*
Visual Appearance	clean; no visible dirt	clean; no visible dirt			
AA Metal Analysis (ppm):					
Iron	5.7	3.7			
Tin	1.4	1.6			
Copper	1.7	1.3			
Aluminum	0.4	0.3			
pH	8.0	8.1	7.7	D-1287	7.5 to 11.0**
RA	7.4 mL	12.mL	14.5 mL	D-1121	10 mL min***
Freeze Point	–7°F	–38°F	–33°F	D-3321	—
Ash (by weight)	0.6%	0.9%	@1.0%****	D-1119	@2.5%**** max
Water (by weight)	59.4%	46.4%	@50%	D-1123	—
Foam/Break Time	40 mL/1.1 sec	47 mL/1.2 sec	42 mL/1.4 sec	D-1881	150 mL/5 sec max
Aluminum Corrosion (mg/cm^2/week)	0.2	0.3	—	D-4340	1.0 max
Cavitation	8	9	—	D-2809	8 min
ASTM D-1384 Corrosion Test (corrected mg loss/ specimen):					
Copper	–1	–1	–1		–10 max
Solder	–20	–30	–10		–30 max
Brass	–5	–4	–2		–10 max
Steel	–1	0	–2		–10 max
Cast Iron	0	+1	0		–10 max
Cast Aluminum	–1	0	–2		–30 max

*Standard specification for Ethylene Glycol Base Coolant[2]
**50% volume in distilled water
***Value for concentrate
****Estimated from specification maximum value.

Looking at the performance tests only, the results showed the recycled sample not to be significantly improved in its corrosion preventing ability over the used sample. The corrosion tests (D-1384) show that both the recycled and the used sample have a propensity for solder corrosion. The remaining metal corrosion losses are very similar and are at acceptable levels as compared to new MIL-A-46153 and the ASTM coolant. In the aluminum corrosion tests (D-4340), both the used and recycled sample gave almost identical results, 0.2 mg/cm^2/week and 0.3 mg/cm^2/week, respectively. The method recommends new antifreeze should have corrosion rates less than 1.0 mg/cm^2/week, and the rates are well below this. The two cavitation tests also produced similar results, with pump ratings of 8 for the used sample and 9 for the recycled sample. The ASTM standard, D-3306 for ethylene glycol base engine coolant, recommends a rating of 8 or higher, and both samples meet this criteria. The foam tests for the used and recycled sample produced substantially the same volume of foam as the new military antifreeze sample. The military specification MIL-A-46153 calls for a maximum foam volume of 150mL and break time of 5sec or less, for new antifreeze. Both samples are well within these limits. The sample quality tests showed the overall cleanliness of the used sample to be comparable to the recycled sample, with no significant differences between the two samples. The RA for the recycled sample was increased to 12.4mL, but a RA of 7.4mL was considered acceptable for the used military antifreeze. The used sample was very clean and therefore the Glyclean system could not improve its condition. The used sample gave comparable results for all tests as compared to the new military antifreeze sample and the recycled sample. This was attributed to the good condition of the used antifreeze and not the effectiveness of the Glyclean system.

During the processing of the Glyclean samples, a problem occurred in determining how much Glyclean additive to use. As stated previously, the Glyclean system uses the Glyclean Extender additive to remove and/or sequester dissolved metals in a used coolant. For the additive to be effective as precipitating agent, the Glyclean instructions state that a pH of 9.5 or higher is needed. This is obtained by adding the additive and checking the pH with pH paper until the desired level is reached. After several additions (i.e., 10.5 gallons) of the Glyclean additive, users at McConnell AFB were unable to obtain pH above 8.0.[5] For the 45 gallons of used antifreeze, which had an initial pH of 7.5, the instructions recommended 1.5 gallons of Glyclean additive be added to

achieve a pH of 9.5. From these results, it was concluded that the high buffering action of the used military antifreeze inhibitor package prevented the pH from rising above 8.0. Apparently, the buffer of the used military antifreeze was still present in a significant amount, indicating an antifreeze in fairly good condition.

This MIL-A-46153 buffer/Glyclean additive interaction was previously observed in BRDEC Letter Report 90-3, "Evaluation of Octagon Antifreeze Cleanup Using a Glyclean Antifreeze Recycler."[4] In that report, an unsuccessful attempt was made to remove dissolved iron from new military antifreeze using the Glyclean additive. The attempt was unsuccessful because proper addition of the Glyclean additive failed to raise the pH above 8.0, thereby rendering the Glyclean additive ineffective as a precipitating agent. For this report, the total effectiveness of the Glyclean Extender additive could not be fully evaluated due to the relatively good condition of the used antifreeze.

KLEER-FLO SYSTEM

The Kleer-Flo unit is assembled as shown in Figure 2. The unit recycles used antifreeze in 25 gallon batches. Unlike the Glyclean system, the Kleer-Flo uses only mechanical filtration to remove contaminants. The used antifreeze is first placed in a "dirty" reservoir located inside the machine. The unit is then started and the old coolant is passed through a series of filters to remove impurities down to a molecular level (i.e., 0.0025 microns). The recycled antifreeze is transferred to a "clean" tank also inside the unit where the solution is reinhibited with Kleer-Flo's proprietary compound, Preparal 25. The Kleer-Flo company states that the system can remove colloidal silica and some suspended metals (i.e., lead suspended as lead oxide and silicate).[6] The system does not, however, remove dissolved metals (i.e., metal ions such as sodium, calcium, and barium). This may or may not be a problem depending on the amount and type of dissolved metal initially present in the used coolant. For example, the presence of 100 ppm iron in new MIL-A-46153 antifreeze was found to make antifreeze/water solutions more corrosive toward aluminum as determined by ASTM glassware corrosion test D-1384.[7]

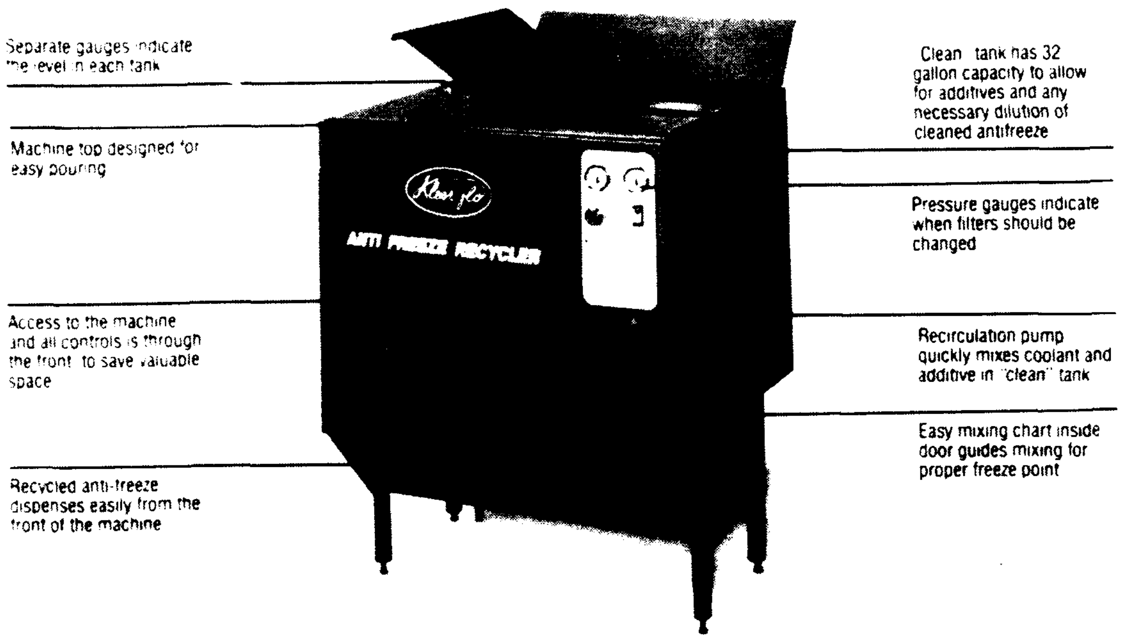

Figure 2. Kleer-Flo Antifreeze Recycling System

The Kleer-Flo samples were collected and processed at Tyndall AFB in Florida. Two batches of samples were tested. The first batch was collected from various vehicles including cars, pickup trucks, and vans. The engine types included both gasoline engines and diesel engines, with the majority being gasoline. Most the of the vehicles were 1979-80 models. All of the vehicles were being retired from previous service and salvaged for parts. The second batch of samples came exclusively from a wet sleeve diesel engine used to power a generator. Tyndall described both batches to be military antifreeze (MIL-A-46153) between one and two years old. Test results of first and second batches of samples processed though the Kleer-Flo system are shown in Tables 2 and 3, respectively.

Table 2. First Kleer-Flo Batch

TEST	USED	RECYCLED	NEW MIL-A-46153	ASTM METHOD	ASTM D-3306*
Visual Appearance	slightly cloudy w/small amount of visible dirt	clean; no visible dirt			
AA Metal Analysis (ppm):					
Iron	1.1	0.3			
Tin	1.5	1.3			
Copper	1.1	0.7			
Aluminum	1.4	0.3			
pH	7.7	7.6	7.7	D-1287	7.5 to 11.0**
RA	10.6 mL	14.4 mL	14.5 mL	D-1121	10 mL min***
Freeze Point	–14°F	–36°F	–33°F	D-3321	—
Ash (by weight)	0.7%	1.0%	@1.0%****	D-1119	@2.5%****max
Water (by weight)	59.1%	47.4%	@50%	D-1123	—
Foam/Break Time	50 mL/1.0 sec	235 mL/10.3 sec	42 mL/1.4 sec	D-1881	150 mL/5 sec max
ASTM D-1384 Corrosion Test (corrected mg loss/specimen):					
Copper	0	+1	–1		–10 max
Solder	–4	0	–10		–30 max
Brass	–2	–2	–2		–10 max
Steel	0	–1	–2		–10 max
Cast Iron	0	+1	0		–10 max
Cast Aluminum	–10	–20	–2		–30 max

*Standard specification for Ethylene Glycol Base Coolant[2]
**50% volume in distilled water
***Value for concentrate
****Estimated from specification maximum value.

Table 3. Second Kleer-Flo Batch

TEST	USED	RECYCLED	NEW MIL-A-46153	ASTM METHOD	ASTM D-3306*
Visual Appearance	cloudy, white flocculent precipitate present	no dirt, but slightly cloudy			
pH	7.4	7.8	7.7	D-1287	7.5 to 11.0**
RA	20.2 mL	21.6 mL	14.5 mL	D-1121	10 mL min ***
Freeze Point	<–55°F	–35°F	–33°F	D-3321	—
Ash (by weight)	0.7%	1.0%	@1.0%****	D-1119	@2.5%****max
Water (by weight)	41.1%	48.8%	@50%	D-1123	—
Foam/Break Time	85 mL/2.4 sec	167 mL/4.8 sec	42 mL/1.4 sec	D-1881	150 mL/5 sec max
ASTM D-1384 Corrosion Test (corrected mg loss/ specimen):					
Copper	–6	–2	–1		–10 max
Solder	–6	–5	–10		–30 max
Brass	–8	–9	–2		–10 max
Steel	–2	–2	–2		–10 max
Cast Iron	–1	–2	0		–10 max
Cast Aluminum	–1	+4	–2		–30 max

*Standard specification for Ethylene Glycol Base Coolant[2]
**50% volume in distilled water
***Value for concentrate
****Estimated from specification maximum value.

Looking at the first batch samples (Table 2), the visual cleanliness of the recycled sample was improved as compared to the used sample, indicating the filtering effectiveness of the system. However, the metal analysis for the used sample indicated very little metal contamination, so the metal removal efficiency of the Kleer-Flo system was not thoroughly tested. The RA and pH of the used sample were both at acceptable levels, though the RA was increased after reinhibition with the Kleer-Flo additive. The RA of 10.6mL for the used sample was considered an acceptable RA for military antifreeze.

For the second batch samples (Table 3), metal analysis was not conducted due to a breakdown of the atomic absorption spectrophotometer. The pH of the used sample was considered to be at an acceptable level, though slightly lower than the recycled sample's pH. This relatively small difference in pH wasn't considered significant. The high RA levels for both the used and recycled sample were attributed to the high antifreeze concentration and/or the used antifreeze solution containing the military extender additive, MIL-A-53009. The military additive is normally added to used military antifreeze, MIL-A-46153, to extend its useful life and it is quite possible the used sample acquired the additive in the field. The recycled sample cleanliness was only improved to slightly cloudy. This was attributed to a precipitate found in the used sample. The precipitate was white in color, flocculent, and floated on the surface of the used antifreeze sample. After a telephone conversation with users at Tyndall AFB, it was found that a white powdery substance formed on the inside surface of the metal holding tanks of the Kleer-Flo unit.[8] Users at Tyndall stated the powder formed while the tanks were empty and appeared to be due to a reaction with the air and not the antifreeze. They also stated that during the processing of the first batch, the same powder was observed but removed from the samples before they were shipped to BRDEC. The precipitate did not interfere during testing, but due to the nature of the precipitate and the potential clogging problems it could cause in a cooling system, Kleer-Flo was contacted to see if the powder was a common occurrence when using the Kleer-Flo unit. A subsequent phone conversation between BRDEC and a Kleer-Flo representative verified the observations at Tyndall.[9] The representative stated that during the production of the first Kleer-Flo units, galvanized steel sheets were used for the holding tanks. The white powder would form in the weld seams after units were allowed to sit undisturbed. Engineers at

Kleer-Flo believed the powder to be an oxide formed by the intense heat used during the welding process. Since then, the problem has been remedied in new units by using a substitute material (i.e., carbon steel). Though the precipitate was not originally in the used sample, its presence and subsequent removal seemed to offer some difficulty for the Kleer-Flo filtration system. This was evidenced by the fact that the recycled sample was cloudy in appearance. This raises the question of whether or not the system will effectively remove contaminants similar in nature that could possibly be found in used antifreeze.

For both batches, the recycled samples exhibited no significant improvement in corrosion test results, as compared to the used samples. This indicated a used sample with sufficient corrosion inhibitors and not necessarily the ineffectiveness of the Kleer-Flo system. However, the results of the foam test indicated that the recycled samples had poorer foaming tendencies than the used samples. The volume and break time of foam for the recycled samples of each batch were considered excessive as compared to foam test results of the original used samples and new MIL-A-46153. From these results, it was concluded that the antifoaming agent still present in the used samples was removed by the filtering process of the Kleer-Flo system, thereby causing the excessive foaming characteristics of the recycled antifreeze. As discussed in the beginning of Section II, excessive foam in a cooling system can cause engine overheating. After discovering the foaming problem, BRDEC notified the Kleer-Flo company.[10] During subsequent phone conversations, it was agreed that the Kleer-Flo process was removing the antifoaming agent from the used antifreeze. A Kleer-Flo representative also stated that the Kleer-Flo additive did not contain antifoam agent but the addition of an agent would be considered.[11] After two months, Kleer-Flo decided to include antifoam agent in their additive compound and sent a sample for an updated foam test evaluation. The results are shown in Table 4.

Table 4. Third Kleer-Flo Batch

Sample 1: Recycled cooiant treated with Kleer-Flo Preparol 25.

Sample 2: Recycled coolant treated with Kleer-Flo Preparol 25 with 0.02% Pluronic L-61 antifoam agent.

Foam Test ASTM D-1881

Sample	Average Foam Volume	Average Break Time
1	340mL	23.9 sec
2	90mL	3.4 sec

The third Kleer-Flo batch sample was not part of the current investigation (i.e., used military antifreeze), but the foam test results here show the previous foaming problem has been eliminated. The addition of the agent should have no effect on the other properties of the recycled antifreeze and presumably the otherwise similar results between the used and recycled Kleer-Flo samples. Therefore, no further testing was conducted on the third batch samples. Combining the improved foam test results with the previous test results, it was concluded that, as with the Glyclean samples, due to the relatively good condition of the used samples, the Kleer-Flo system effectiveness was not fully tested.

WYNN SYSTEM

The Wynn unit comes assembled as shown in Figure 3. The unit processes used antifreeze for individual vehicles as opposed to batch type processing of the other two recycling systems. The unit uses a "closed loop" attachment to the vehicle's cooling system. This "closed loop" system incorporates mechanical filtration and chemical additions to remove corrosives and particulates.[12] Like the Glyclean system, the Wynn system uses precipitating agents to precipitate soluble metals in the used coolant. The Wynn system uses organic polymers to precipitate dissolved metals, while the Glyclean system uses sodium hydroxide. Unlike the Glyclean system, however, the precipitating agents and inhibitor additives are added as separate

solutions. After the metals are precipitated, they are removed from solution by filters in the Wynn unit. This is then followed by reinhibition with a proprietary additive compound.

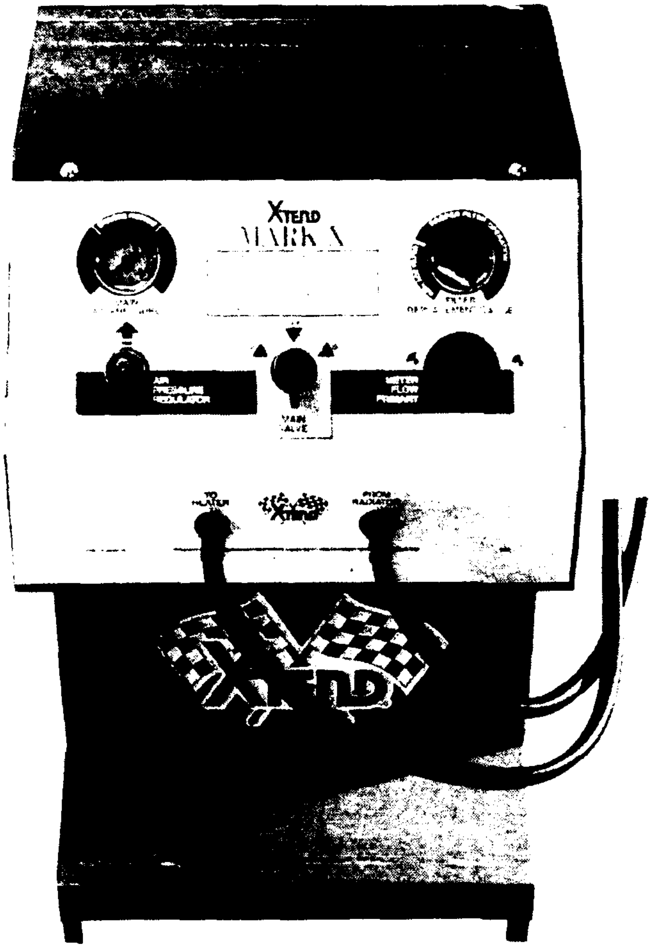

Figure 3. Wynn Antifreeze Recycling System

Wynn samples were processed at McConnell AFB. Initially, one set of samples taken from two Ford trucks was tested. The first used sample was military antifreeze MIL-A-46153 believed to be at least two years old. The age of the second sample was unknown, but users believed it to be MIL-A-46153. Due to the single vehicle processing of the Wynn system, only a limited amount of test samples could be obtained from McConnell. Therefore, a second set of samples, taken from two rental vehicles, was obtained from Wynn Oil Company. The age and brand of the antifreeze were unknown. A Wynn official believed the samples could have been either original engine manufacturer (OEM) or commercial brand. The test results of samples processed through the Wynn system are shown in Tables 5, 6, 7, and 8.

Table 5. First Wynn Batch—First Used Sample
(used antifreeze from Ford truck, MIL-A-46153, at least 2 years old)

TEST	USED	RECYCLED	NEW MIL-A-46153	ASTM METHOD	ASTM D-3306*
Visual Appearance	slightly cloudy, w/small amount of visible dirt	clean, no visible dirt			
pH	7.1	7.2	7.7	D-1287	7.5 to 11.0**
RA	19.0 mL	19.4 mL	14.5 mL	D-1121	10 mL min ***
Freeze Point	—	—	–33°F	D-3321	—
Ash (by weight)	1.2%	1.4%	@1.0%****	D-1119	@2.5%****max
Water (by weight)	26.6%	30.4%	@50%	D-1123	—
Foam/Break Time	—	—	42 mL/1.4 sec	D-1881	150 mL/5 sec max
ASTM D-1384 Corrosion Test (corrected mg loss/specimen):					
Copper	–1	– 8	–1		–10 max
Solder	+1	– 7	–10		–30 max
Brass	–3	–13	–2		–10 max
Steel	–4	– 1	–2		–10 max
Cast Iron	–1	– 3	0		–10 max
Cast Aluminum	+1	– 4	–2		–30 max

*Standard specification for Ethylene Glycol Base Coolant[2]
**50% volume in distilled water
***Value for concentrate
****Estimated from specification maximum value.

Table 6. First Wynn Batch—Second Used Sample
(used antifreeze from Ford truck, MIL-A-46153, age unknown)

TEST	USED	RECYCLED	NEW MIL-A-46153	ASTM METHOD	ASTM D-3306*
Visual Appearance	slightly cloudy, w/small amount of visible dirt	clean, no visible dirt			
pH	6.9	7.3	7.7	D-1287	7.5 to 11.0**
RA	23.3 mL	21.3 mL	14.5 mL	D-1121	10 mL min ***
Freeze Point	—	—	–33°F	D-3321	—
Ash (by weight)	1.2%	1.5%	@1.0%****	D-1119	@2.5%****max
Water (by weight)	15.5%	29.2%	@50%	D-1123	—
Foam/Break Time	—	—	42 mL/1.4 sec	D-1881	150 mL/5 sec max
ASTM D-1384 Corrosion Test (corrected mg loss/ specimen):					
Copper	– 1	– 7	– 1		–10 max
Solder	–154	–38	–10		–30 max
Brass	– 1	–13	– 2		–10 max
Steel	– 1	– 1	– 2		–10 max
Cast Iron	– 1	– 1	0		–10 max
Cast Aluminum	+ 1	– 3	– 2		–30 max

*Standard specification for Ethylene Glycol Base Coolant[2]
**50% volume in distilled water
***Value for concentrate
****Estimated from specification maximum value.

Table 7. Second Wynn Batch—First Used Sample (unknown commercial brand from 1985 Fort Mustang with 96,373 miles; age of coolant unknown)

TEST	USED	RECYCLED	NEW MIL-A-46153	ASTM METHOD	ASTM D-3306*
Visual Appearance	cloudy, no visible dirt	clear, no visible dirt present			
pH	9.3	10.6	7.7	D-1287	7.5 to 11.0**
RA	4.4 mL	10.8 mL	14.5 mL	D-1121	10 mL min ***
Freeze Point	+14°F	—	–33°F	D-3321	—
Ash (by weight)	—	—	@1.0%****	D-1119	@2.5%****max
Water (by weight)	77.6%	34.7%	@50%	D-1123	—
Foam/Break Time	—	43mL/0.9 sec	42 mL/1.4 sec	D-1881	150 mL/5 sec max
ASTM D-1384 Corrosion Test (corrected mg loss/ specimen):					
Copper	–2	–4	– 1		–10 max
Solder	0	0	–10		–30 max
Brass	–5	+1	– 2		–10 max
Steel	–2	0	– 3		–10 max
Cast Iron	–2	+1	0		–10 max
Cast Aluminum	–8	+4	– 2		–30 max

*Standard specification for Ethylene Glycol Base Coolant[2]
**50% volume in distilled water
***Value for concentrate
****Estimated from specification maximum value.

Table 8. Second Wynn Batch—Second Used Sample (unknown commercial brand from 1985 Fort Mustang with 44,624 miles; age of coolant unknown)

TEST	USED	RECYCLED	NEW MIL-A-46153	ASTM METHOD	ASTM D-3306*
Visual Appearance	clear, no visible dirt present	clear, no visible dirt present			
pH	8.9	10.4	7.7	D-1287	7.5 to 11.0**
RA	4.0 mL	10.7 mL	14.5 mL	D-1121	10 mL min***
Freeze Point	–5°F	—	–33°F	D-3321	—
Ash (by weight)	—	—	@1.0%****	D-1119	@2.5%****max
Water (by weight)	61.6%	36.7%	@50%	D-1123	—
Foam/Break Time	—	20 mL/0.9 sec	42 mL/1.4 sec	D-1881	150 mL/5 sec max
ASTM D-1384 Corrosion Test (corrected mg loss/ specimen):					
Copper	–2	–5	– 1		–10 max
Solder	–5	–2	–10		–30 max
Brass	–6	–2	– 2		–10 max
Steel	–2	+1	– 3		–10 max
Cast Iron	–2	+1	0		–10 max
Cast Aluminum	–1	+2	– 2		–30 max

*Standard specification for Ethylene Glycol Base Coolant[2]
**50% volume in distilled water
***Value for concentrate
****Estimated from specification maximum value.

For the first batch of Wynn samples from McConnell AFB, the foam test, the ash content, and the metal analysis were not performed due to the limited amount of sample available. Also due to the limited sample size, the glassware corrosion test, ASTM D-1384, could not be run in triplicate as prescribed in the method, and the results are therefore representative of only one test solution. The freeze protection could not be determined using ASTM practice D-3321 due to the large concentration of ethylene glycol. The procedure was designed for antifreeze solutions containing 0 to 56% by volume of antifreeze concentrate. The remaining test results for the first sample indicated no significant improvement of the recycled sample over the used sample. The corrosion test data actually showed a slight decrease in protection for the copper, brass, and solder specimens. The high RAs for both the used and recycled samples were attributed to the high antifreeze concentration and the used sample having a considerable amount of its inhibitor package still intact. The pH for both samples was considered acceptable. The recycled cleanliness was greatly improved over that of the used sample, indicating an effective filtration system.

The second used military sample of the first Wynn batch gave very poor corrosion results for the solder specimen. The recycled sample improved the solder corrosion considerably, but the weight loss was still greater than the recommended loss for the ASTM coolant or the new military sample. For both samples, the increased solder corrosion was due to the high antifreeze concentration and not the Wynn system effectiveness. For example, the concentrations were approximately 86% for the used sample and 70% for the recycled sample. The large amount of antifreeze concentrate decreased the corrosion protection of the solutions, especially the used sample with 86% antifreeze. In general, most ethylene glycol base coolants provide their best corrosion protection between 50 and 70% concentration by volume. Again, as with the first sample, the pH and RA for the used sample and the recycled sample were indicative of the large antifreeze concentrations of both samples, and the used sample having a considerable amount of its inhibitor package still intact. The overall cleanliness of recycled sample was the only test parameter significantly improved.

For the second batch of samples obtained from the Wynn Oil Company, small sample sizes again limited the number of tests conducted. The ash content, metal analysis, and the foam test could not be conducted on the used samples. The corrosion test for the used samples was conducted using only one test solution. The corrosion tests performed on the recycled samples were run in triplicate as the method prescribes. Additional solution was made available by adding distilled water to make 50-50 solutions. This was done to help obtain comparable corrosion results with the used samples whose water concentrations were approximately 78 and 62% by volume. For the remaining tests—pH, freeze protection, RA, visual appearance, and foam—the recycled samples were run as received. The test results of both Wynn recycled samples displayed no significant improvement as compared to the used samples. Both the first and second recycled sample RAs were increased, but the increase was mostly attributed to the decreased water concentration and not the reinhibition with the Wynn additives. The glassware corrosion results for both used samples were similar to their respective recycled sample. All four samples gave corrosion results comparable to MIL-A-46153 and the ASTM coolant results. The first used sample's cleanliness was upgraded from cloudy to clear, but the remaining tests results were not substantially different from the recycled sample. The large differences in pH and RA between the test samples and new MIL-A-46153 were due to the dissimilar inhibitor packages found in commercial and military antifreezes. After considering data from both Wynn batches, it was concluded that, as with the previous recycling systems, due to the relatively good condition of the used samples, the Wynn system effectiveness was not thoroughly tested.

Section III
Conclusions

Results of all testing are shown in Table 9. Due to the varying degree of used antifreeze condition among the test samples, direct comparison of each recycling unit to the other was not made. However, all three recycling units had similar levels of effectiveness. For example, the majority of recycled product from each unit showed no substantial improvement in quality over the original used product. Some parameters, like pH and RA, were improved, but these improvements were mostly attributed to the addition of new antifreeze concentrate to lower the recycled sample freeze point and not to recycling method effectiveness. The adding of new antifreeze concentrate to increase freeze protection was the standard practice for each recycling system.

Though the test results of the recycled antifreeze samples are good, the results reflect the good condition of the used samples and not the effectiveness of the recycling systems in this study. At this time, BRDEC recommends that recycled antifreeze not be used in military vehicles until more severe testing can be conducted to truly test the effectiveness of the recycling systems. The use of recycling units without further study could be a serious waste of money on systems which aren't needed if the used coolant is still in satisfactory condition. Vehicle damage could also result from the use of poor quality recycled antifreeze. These recommendations are not meant to indicate the units are ineffective, but to clearly state the uncertainty of their usefulness at this time.

For the next investigation, the test samples will be limited to used MIL-A-46153 antifreeze, preferably in depleted condition that needs to be changed. The antifreeze corrosion test kit, A-A-51461, could be initially used to determine antifreeze which is unfit for use (i.e., test strip turning yellow after insertion into antifreeze solution). This test kit is made specifically for MIL-A-46153's additive package so its use would be limited to military antifreeze.

Table 9. Summary of Results

Glyclean System	pH	RA	Freeze Point	Ash	Water	Foam/ Break time	Aluminum Corrosion	Cavitation
used	8.0	7.4 mL	–7°F	0.6%	59.4%	40 mL/1.1 sec	0.2mg/cm²/week	8
recycled	8.1	12.4 mL	–38°F	0.9%	46.4%	47 mL/1.2 sec	0.3mg/cm²/week	9
Kleer-Flo System								
used 1	7.7	10.6 mL	–14°F	0.7%	59.1%	50 mL/1.0 sec		
recycled 1	7.6	14.4 mL	–36°F	1.0%	47.4%	235 mL/10.3 sec		
used 2	7.4	20.2 mL	<–55°F	0.7%	41.1%	85 mL/2.4 sec		
recycled 2	7.8	21.6 mL	–35°F	1.0%	48.8%	167 mL/4.8 sec		
used 3	—	—	—	—	—	340 mL/23.9 sec		
recycled 3	—	—	—	—	—	90 mL/3.4 sec		
Wynn System								
used 1	7.1	19.0 mL	—	1.2%	26.6%	*		
recycled 1	7.2	19.4 mL	—	1.4%	30.4%	*		
used 2	6.9	23.3 mL	—	1.2%	15.5%	*		
recycled 2	7.3	21.3 mL	—	1.5%	29.2%	*		
used 3	9.3	4.4 mL	+14°F	*	77.6%	*		
recycled 3	10.6	10.8 mL	**	*	34.7%	43 mL/0.9 sec		
used 4	8.9	4.0 mL	–5°F	*	61.6%	*		
recycled 4	10.4	10.7 mL	**	*	36.7%	20mL/0.9 sec		
New MIL-A-46153	7.7	14.5 mL	–33°F	@1.0%***	@50%	42 mL/1.4 sec		

*Test not conducted because of lack of sample

**Antifreeze concentration exceeded refractometer limits

***Estimated from specification maximum

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